INRIA Associate Team
VanaWeb: *Hybrid and autonomous constraint solving and applications to composition problems for the Web*
Final report

`http://www.loria.fr/~ringeiss/CHILI/vanaweb`

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1 Partnership

- UTFSM, Valparaíso: Carlos Castro, Eric Monfroy, Maria-Cristina Riff, Broderick Crawford (PhD student)
- INRIA Nancy Grand Est — Cassis, Score and Pareo teams: Christophe Ringeissen (Cassis), Laurent Vigneron (Cassis), Olivier Perrin (Score), Horatiu Cirstea (Pareo), Pierre-Etienne Moreau (Pareo)
- Academic partners: Frédéric Saubion (U. Angers), Arnaud Lallouet (U. Caen)

2 Scientific Report

2.1 Summarize the initial objectives of the project

We are interested in constraint modeling and in the development of constraint solvers based on the combination of complete methods, incomplete methods and autonomous exploration strategies. Our originality

relies on a hybrid and autonomous approach that allows us to enhance both the expressiveness and the efficiency of solvers, to obtain better solutions, to solve distributed systems, and to ease the development of solvers since less expertise is needed. In this context, we investigate on different topics: formal frameworks, rule languages (controlled by strategies), cooperation techniques, interoperability and dynamic control of solvers. We are targeting some applications related to composition problems for the Web. We are focusing on the composition of Web services and the composition of documents, where our hybrid, autonomous, and multi-criteria constraint solving techniques seem very useful.

2.2 Did the goals shifted along the completion of the project?

The project is the continuation of a well-established collaboration: Carlos Castro, Eric Monfroy, Olivier Perrin, Christophe Ringeissen, Laurent Vigneron did their PhD theses at CRIN-INRIA (Nancy) in the 90's, and share a common research interest on constraint and rule technologies. When Carlos Castro came back to Chile, we started a collaboration on constraints, rules, and strategies. A major side-effect of this collaboration is that Eric Monfroy, who was professor at Nantes, has moved to Valparaíso, to work with Carlos Castro at UTFSM. Our collaboration has been successively supported by different INRIA-CONICYT projects, namely COCARS, VANANAA and CoreWeb. In the last years, the collaboration has been extended to French colleagues working on hybrid methods (Frédéric Saubion, prof. univ. Angers) and quantified constraint satisfaction problems (Arnaud Lallouet, prof. univ. Caen).

The research project is currently divided into the following tasks:

1. Hybrid and autonomous solving: dynamic solvers interaction via adaptive strategies

2. Constraint modeling for the composition of Web services

3. Constraint optimization for the composition of documents

4. Quantified constraint satisfaction problems applied to the composition of Web services

This first task is a natural extension of the research conducted within the joint INRIA-CONICYT project VANANAA (funded until 2007), where the goal is to improve and generalize the ideas initially developed for hybrid and reactive solving. Hybridization of different solving techniques has led us to consider more general cooperation and control purposes in the design of new solvers. Therefore, we have developed several works concerning the definition of adaptive strategies and control tools for solving constraint optimization problems. Constraint solving techniques are indeed the basic technologies of the applications developed in this project.

In Tasks 2, 3 (see above), we study how our specification and constraint solving methods can be applied to composition problems for the Web. These two tasks rely on an INRIA-CONICYT project CoreWeb funded since 2007.

In 2009, we have started to work on Quantified Constraint Satisfaction problems (QCSP) and their potential applications to the execution and the verification of compositions of services.

2.3 Describe the scientific results of the project (maximum 3 pages)

2.3.1 Autonomous search

Combinatorial problems are often modeled as Constraint Satisfaction Problems or constraint optimization problems, which consist of a set of variables, a set of possible values for these variables and a set of constraints to be satisfied. However, solvers or hybridization of solvers become more and more complex: the user must select various solving and hybridization strategies and tune numerous parameters. Moreover, it is well-known that an a priori decision concerning strategies and parameters is very difficult since strategies and parameters effects are rather unpredictable and may change during resolution. The selection and the correct setting of the most suitable algorithm for solving a given problem has already been investigated many years ago [21] and leads to two important tasks : 1) selecting solving techniques or algorithms from

a set of possible available techniques, and 2) tuning an algorithm with respect to a given instance of a problem. Moreover, setting should be changed to adapt themselves to the process during solving. An Autonomous Search [Hamadi et al., 2011] system should provide the ability to advantageously modify its internal components when exposed to changing external forces and opportunities.

Internal components correspond to the various algorithms involved in the search process — heuristics, inference mechanisms, etc. External forces correspond to the evolving information collected during this search process — search landscape analysis (quality, diversity, entropy, ...), external knowledge (prediction models, rules, ...), etc . This information can be either directly extracted from the problem or indirectly computed through the perceived efficiency of algorithm's components.

Autonomous search, bases and classification. In order to settle the bases of this new research topic in development, we have organized the first workshop on Autonomous Search in 2007 (co-located with international conference CP), and edited a special issue on the topic [Hamadi et al., 2008]. We have also written a chapter for a book [Hamadi et al., 2009], and we are in the final phase (polishing the final version) of the edition of a book about Autonomous Search to be published by Springer in 2010 [Hamadi et al., 2011].

Automated tuning of parameters and operators. After some previous works on parameter automated control for genetic algorithms [MS08, MS07a, MS07b], we have developed more sophisticated control tools [MFS$^+$09, MLS09], and we have proposed a methodology to dynamically manage the operators integrated in the algorithm [MLS10]. This approach can be extended for other solving techniques, and more especially to manage heuristics in a complete constraint solver. Jorge Maturana, who was a Chilean student from the UTFSM, funded by CONICYT, worked on this topic and defended his PhD thesis in the LERIA of Angers in June 2009. He his now professor at the University of Valdivia (Chile).

Strategy and Autonomy for hybridization. In [CMFM05, MCC06], we proposed a framework for adaptive enumeration strategies and meta-backtracks for a propagation-based constraint solver. We then extended this framework in order to trigger some functions of a solver, or of an hybrid solver to respond to some observations of the solving process. Hence, we can also simply design adaptive hybridization strategies by just changing some few rules of our framework. We experimented this framework on an hybrid BB+propagation solver in which propagation can be triggered w.r.t. some observations of the solving process [MCCF10] (and [MCCFa] for other strategies). The results show that some phases of propagation are beneficial to the BB algorithm, but also that propagation is too costly to be executed at each node of the search tree. The hybridization strategies are thus crucial in order to "tune" when to perform or not propagation. We are currently working on a journal article to present details of the framework [CMFM], and another journal article to present the complete set of hybridization strategies we have realized [MCCFb]. Both papers will be submitted before the end of september.

In parallel, we have also worked on other kinds of hybridization of solving methods, i.e., metaheuristics, hyperheuristics, and constraint programming [CCM10a, CCM10c, CCM10b].

Formal aspects of modeling and solving for CSP. In order to develop powerful hybrid adaptive solvers, we have also studied precisely the basic solving mechanism involved in the solving processes. In this context, we have develop transformation techniques for modeling constraint problems in SAT/CSP formalism and we have thus defined extended solving rules [Lardeux et al., 2008b, Lardeux et al., 2008a, Lardeux et al., 2009b, Lardeux et al., 2009a] for improving constraint propagation. On the other hand, in order to use local search techniques in constraint solvers, we needed a formal model of the solving processes [Monfroy et al., 2008e, Monfroy et al., 2008f, Monfroy et al., 2008d]. These works are directly connected to our recent advances in autonomous and adaptive solving where the understanding of the basic solving mechanism is a key feature.

2.3.2 Composition of Web services: application of constraint reasoning

Composition of Web services has been recently investigated from various points of view by developing different approaches based for instance on planning techniques, logical systems and appropriate transition systems. There are few papers reporting experiments on the use of constraint reasoning for the composition problem [15, 14, 7, 8, 17, 16].

For instance, in [8], the idea is to consider the composition problem as a particular constraint-based configuration problem. Our approach is based on a distributed framework to build a composition for a given task. We use constraints to model (in a declarative way) various properties of services. A solver associated to each service is in charge of finding the right concrete services that are able to perform a given task with respect to various requirements expressed as constraints. At that point, a natural problem arises: how these different solvers can be combined together in order to build a composition performing this task? We address this problem in the paper by considering a simple form of composition, where (a pattern of) the composition is instantiated in an incremental way with a selection of services guided by solvers. Our contribution is to present an event-based distributed framework for the composition of services. We develop the main algorithms to construct a composition thanks to solvers and backtrack mechanisms used in a distributed way. In this distributed framework, each service is building a part of the full composition.

All these ideas are discussed in a first joint paper [Monfroy et al., 2008b, Monfroy et al., 2008c]. A second paper [Monfroy et al., 2008a] focuses on the description of the algorithms for building the composition via the solvers associated to the services.

Our framework is inspired from [15]. Similarly to [15], we also assume that a pattern of composition is given, and we restrict us to the problem of instantiating the variables of this pattern, i.e., the different kinds of Web services. Contrary to [15], we do not consider constraints globally, but we handle constraints locally in order to build a solution gradually using a top-down mechanism. Our framework has the ability to tackle privacy requirements (as opposed to [15]) by considering only public properties of possible sub-services, by limiting exchange of data, and by keeping locally most of the knowledge.

2.3.3 Optimization Techniques for Information Retrieval

During recent years, information retrieval field has been extended to the development of applications whose purpose is not only to help the user to retrieve relevant documents, but also to provide a synthetic answer as a response to the information needs he expressed.

In this context, we have focused on the production of composite documents, representing an overview of the different types of information that the user can find, in connection with his request, in the corpus in concern. After being concerned about the method of extraction and selection of fragments of text to be included in the composite document, the problem can be viewed as a combinatorial optimization problem and we have developed a multi-objective algorithm, which aims at finding the thematic segments subset maximizing two criteria of query proximity and thematic representativeness. Beyond the composite document conception, the realized contributions concern the thematic segmentation and its evaluation, the relevance estimations and similarity computations, the impact of the thematic individualization in the field of information retrieval, the evaluation of systems presenting search results in term of a clusters set and, at last, the ways of query consideration in texts clustering process.

This work clearly illustrate how optimization techniques can be efficiently used to improve text clustering algorithm and to provide efficient tools for information retrieval [LALS07b, LALS07c, LALS07d, LALS07a, LALS08d, LALS08f, LALS08e, LALS08c, LALS08a, LALS08b, LALS09, LASL10b, LASL10a].

2.3.4 Quantified Constraint Satisfaction Problems

QSCP have proven useful in modeling complex game-related problems with constraints [BM02, BLV07, BLV08a] [19, 13, 20]. So far, the framework considered involves two competing agents, say the Verifier and the Falsifier, as in Game Theory. The Verifier owns the existential quantifier and is the agent from which the problem is seen. In particular, the winning condition of the game is written from the point of view of

the Verifier. The Verifier tries to find a solution to the problem which satisfies the constraints of its winning condition. In contrast, the Falsifier is defined relatively to the Verifier and is assumed to have a strictly reversed winning condition. A solution of such a problem is called a strategy and defines a behavior for the Verifier in function of the moves of the Falsifier. In [BLV08b], both agents may have different conflicting objectives but it is not mandatory that one should be the exact opposite of the other.

The two-agents framework is not sufficient since many real-life problems are intrinsically formulated in a multi-agent setting (that is not easily reducible to the two-agents case). However, many concepts do not seem to extend easily to the multi-agent case. We thus proposed to extend the framework of QCSP to n agents, by retaining as much as possible of the initial framework and its main advantages (namely the ability of modeling with constraints), and to provide:

- privacy to the agents, so that they can hide some pieces of information such as their behaviors, their strategies, or the strategies they suppose their adversaries have;
- not only the possibility of non opposite objectives, but also cooperation of some of the players in order to serve their own interests.

The interest of this framework is that it seems very well suited to web services: a player becomes a service, its moves become its actions, its goal is the achievement of a task (common to several services), and its privacy is made of its internal data, its private constraints, ...

Various strategies (in terms of game theory) could be computed or verified, for examples:

- to develop a service composition achieving a common task;
- to verify a deadlock-free communication protocol;
- to verify that some data being exchanged (i.e., public data or shared data) are sufficient to obtain a winning global strategy (i.e., the achievement of a task);

In a first phase, while Arnaud Lallouet was visiting UTFSM in Valparaíso (in 2009), we have studied the modifications required by the two players framework in order to extend it to a multi player framework in which players do not have necessarily opposite winning conditions. We have identified the need of extending the notion of quantifier: for two players, the Verifier is existentially quantified and the Falsifier is universally quantified; in a multi player framework, each player must have a different quantifier. Each player also has a different interpretation of the global formula (quantifier and logic connectors): during solving (i.e., computing the strategies) quantifiers and connectors are instantiated differently w.r.t. the various points of view of the players. We have also identified that privacy can be treated by "typing" constraints: public and private constraints. The private constraints of a service/player are only used when "reasoning" as the player that owns these constraints. We are currently working on an article on this subject, containing the required syntax, the formulation of the interpretations of the players, and the solving techniques (i.e., the computation of strategies).

On the other hand, solving such problems is a relatively new research domain and QCSP are PSPACE complete: this is thus challenging in terms of solving and of a much higher magnitude than classic CSP. It is thus necessary to re-design the cutting techniques and the evaluation algorithms. But it is even more important to develop good heuristics. Moreover, the distributed nature of the problem makes these heuristics difficult to understand, and thus makes them good candidates for autonomous search techniques like those also studied in this project.

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3 Outcome of the collaboration

3.1 List the joint papers published by members of the Associate Team

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3.2 List the thesis supervised within the context of the Associate Team

- Jorge Maturana, a former student from the UTFSM, did a PhD thesis at the university of Angers, on generic control for evolutionary algorithms [MFS+09, MLS09, MLS10], under the supervision of Frédéric Saubion. Jorge Maturana is now professor at the university of Valdivia, Chile.
- Nawal Guermouche did a PhD thesis at the university of Nancy, on Web services composition [GPR08b, GPR08a].
- Broderick Crawford is currently doing his PhD thesis at the UTFSM on solver hybridization and autonomous search.

3.3 What is your assessment of the collaboration, and its added value for the research conducted within your INRIA project-team ?

We have obtained some very significant results in two directions:

- We have promoted the field of autonomous search in the constraint community. Several joint publications show our involvement in this activity [Hamadi et al., 2008, Hamadi et al., 2009, Hamadi et al., 2011].
- We have explored some very appealing Web-oriented problems (composition of Web services, information retrieval), by showing the interest of modeling with constraints and QCSPs.

The initial goals of the project were very ambitious, and there are a lot of ongoing developments. Briefly, we still have to strengthen the developed frameworks and to develop a significant tool support.

This project is a good opportunity to start working on some new topics, to prepare the future of the INRIA project-team CASSIS. In this direction, the idea is to move from the verification of protocols (one of the initial goals of CASSIS) to verification problems occurring in Service Oriented Computing (SOC) and in Web technology. Our involvement in recent research projects shows this evolution. Indeed, we participate to the European FP7 project AVANTSSAR[1] and to the project COPS[2] funded by the French National Research Agency (ANR). Both projects are related to the security of services. The work conducted within the associate team also contributes to prepare the future of CASSIS, by starting to work on applications of constraint technology to solve (verification) problems occurring in SOC.

Besides the study of new application domains, the associate team allows us to support the networking with French and Chilean colleagues having common research interests on Constraint, Rule and Web technologies.

This project also helped to initiate new research projects related to the topics of VanaWeb: Two partners of the team (F. Saubion, from univ. Angers, and E. Monfroy, from UTFSM) proposed a ECOS-CONICYT project with the university of Valdivia about a special case of autonomous search (i.e., Autonomous Evolutionary Algorithms). This project is currently under evaluation. The same partners are also participating in TODAS a new STIC-Amsud project accepted in 2010. This project also involves INRIA Roquencourt (F. Fages, P. Deransart, from INRIA team-project CONTRAINTES). The goal of this project is to use solving trace in order to improve autonomy of the solver.

In the context of the project, we organize a joint TODAS/VanaWeb/Coreweb workshop on "Constraint Solving and Tracing, Application to Web services" to be held in Valparaíso in November 2010.

One may notice that an article presenting our project VanaWeb/CoreWeb has been published in the monthly newsletter of the USM[3] (April 2010, page 12).

[1] http://www.avantssar.eu
[2] http://www.irit.fr/COPS/Accueil.htm
[3] http://www.usmperiodico.cl

3.4 Do you foresee further developments for this collaboration?

In the future we would like to continue our investigations on cross-fertilizing interactions between some background techniques (autonomous search, hybrid methods, multi-criteria optimization, quantified CSPs, combination methods) and synthesis (composition) problems we have identified during the last years. We foresee the following research directions:

Hybridization and Autonomous search: We want to continue our basic research on autonomous search by focusing on the following topics:

- Combine Angers approach (for evolutionary algorithms) and UTFSM approach (for adaptive enumeration strategy) for fine grain autonomous propagation based constraint solver (autonomy for both enumeration and propagation operators)
- Develop a methodology and an algorithmic framework to design autonomous solvers
- Define a more sophisticated strategy language for hybridization integrating overlapping global constraints

Constraint-based service composition: We plan to continue the development of our constraint-based service composition framework by focusing on the following topics:

- Clarify the constraint languages that can be used to express the requests handled by services.
- Relate our framework with existing tools, especially those based on planning.
- Instantiate the framework with powerful constraint solvers (like those related to autonomous search and QCSPs).
- Integrate transactional aspects and monitoring features to get adaptative compositions of services.
- Parameterize the framework, to change the scope of solvers, so that a solver is not necessarily associated to only one service.
- Give a formal specification of the framework, using for instance a rule-based formalism. A long-term issue would be to apply formal methods for verifying properties of the framework (seen as a complex system).

Currently, we disregard the means used to exchange the information between services. In the future, it would be interesting to guarantee some security properties during the construction of the composition. This aspect will be considered in a future extension of our basic framework. Moreover, we would like to introduce a monitoring mechanism for analyzing the execution of a composition, in order to perform a re-instantiation when a problem occurs.

Our initial motivation was to consider composition problem as (constraint) satisfiability problems. Focusing on such synthesis problems is clearly a very appealing but risky activity. After this first phase, we want now to address also (simpler) verification problems that occur when an existing composition is analysed/monitored.

Composition of documents: In the extension of our work on the thematic segmentation and the automatic composition of documents, we envision to study the stylistic aspects of documents. Similarly to thematic segmentation, our approach consists in considering this problem as a multi-criteria optimization problem to divide the documents and to merge the resulting parts according to stylistic criteria. Optimization techniques and constraint programming should then allow us to identify classes and styles, and so to automatically identify the authors. Therefore, this could be useful to detect plagiarism, which is an increasingly important issue on the Web. Moreover, since our goal is still the automatic composition of documents, this approach will allow us also to standardize the style of responses to improve the quality of the answer provided to the user through an information search.

Quantified Constraint Satisfaction Problems: This research direction has been recently initiated within the associate team. In the near future we want to address the following issues in connection with composition problems we are interested in:

- Specify a constraint language (with a syntax à la QCSP) for describing multi-players framework including private and public constraints.
- Formalize the interpretations of the various players.
- Develop new solving techniques, possibly based on metaheuristics.
- Formalize the problem as a web service composition.

CIRIC proposal: We are associated to the project of building an INRIA Lab in Chile (CIRIC centre of excellence). We are involved in the line "Models and software for high impact indutries", and more precisely in the sub-line "Models and Algorithms" (head of the subline: Jorge Amaya), in which we find partners from Santiago (CMM,DCC, Delphos Lab), Valparaíso (UTFSM) and INRIA. The goal is to develop new mathematical models and tool support for the mining industry, by using integer programming, metaheuristics, constraint programming... In this context, we plan to study how to apply our solving methods and our constraint modeling expertise on composition problems.